A REVIEW OF FLOW AND TEMPERATURE MODELING LITERATURE

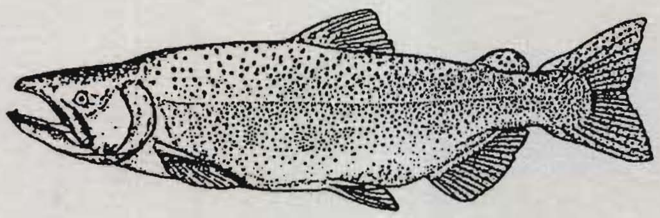
Prepared by the

Division of Ecological Services

U.S. Fish and Wildlife Service

for the

CENTRAL VALLEY PROJECT IMPROVEMENT ACT FISH RESTORATION PROGRAM



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INTRODUCTION

The Central Valley Project Improvement Act (CVPIA) created the Central Valley Anadromous Fish Restoration Program to develop and implement a program which makes all reasonable efforts to ensure that, by the year 2002, the natural production of anadromous fish in all Central Valley streams will be sustainable at levels not less than twice the average levels attained during the 1967-91 period (see USFWS, 1993a). The program is to be developed by 30 October 1995. The CVPIA states that flows of suitable quality, quantity, and timing are to be provided to protect all life stages of anadromous fish found in streams controlled by the Central Valley Project. These flows will be determined by the U.S. Fish and Wildlife Service (USFWS) in consultation with the California Department of Fish and Game (CDFG). Anadromous species specifically identified in the CVPIA are chinook salmon (*Oncorhynchus tshawytscha*), steelhead trout (*Oncorhynchus mykiss)*, green and white sturgeon (*Acipenser medirostris* and *A. transmontanus*), striped bass (*Morone saxatilis*), and American shad (*Alosa sapidissima*). The objective of this report is to identify instream flow and temperature studies which have been conducted for the anadromous fisheries in Central Valley streams; and to recommend additional investigations which might be useful for achieving the goals of the CVPIA fish restoration program. Central Valley streams not controlled by the Central Valley Project, but supporting anadromous fish are also covered in this report. Most of the studies considered runs of chinook salmon. A few considered steelhead trout, and fewer still, American shad and striped bass. While green and white sturgeon are found in the Sacramento and San Joaquin systems, their flow needs have not been examined.

UPPER SACRAMENTO RIVER

Study

California Department of Water Resources. **1993b**. Upper Sacramento River habitat modeling progress report end of phase 1. California Department of Water Resources Northern District. Technical information report, TIR ND-93-01. 66 pp.

Study Summary. This study was the first phase of a multiple phase project to determine the instream flow needs of chinook salmon inhabiting the upper Sacramento River from Keswick Dam to Hamilton City. This report documents the first major attempt to study fish habitat versus streamflow on the Sacramento River. The study was funded and performed under joint agreement between the CDFG and the California Department of Water Resources (CDWR).

The Physical Habitat Simulation (PHABSIM) component of the USFWS' Instream Flow Incremental Methodology (IFIM) was used to predict the available microhabitat for all life stages of fall-run chinook salmon over a range of flows. Although concern was expressed for other salmon runs and steelhead trout, they were not included as evaluation species. Fall-run chinook salmon habitat suitability criteria (HSC) were developed within the study area by CDFG (see Brown, 1990).

It was anticipated that this study would serve as a first step in a process leading to a multi-agency recommendation for modified flow releases on the Sacramento River. Further investigations necessary to formulate such recommendations are identified by CDWR (1993b) and CDFG (Brown, 1990). However, additional investigations have not been conducted (B. Mendenhall, pers. comm.)

Study

Beak Consultants Inc. **1992**. Fish and wildlife investigations for Folsom Dam reoperation. Prep. for U.S. Army Corps of Engineers.

Study Summary. The Sacramento River from Keswick Dam to the confluence with the American River was modeled using the QUAL2E water temperature model. An hourly time step and three mile reaches were used. Flow adjustments were made at the Red Bluff Diversion Dam, Butte City, and Wilkins Slough to account for accretions and depletions. The model was calibrated to simulate the general water temperature and diurnal fluctuations.

Study

Brown, C. **1990**. Determination of habitat preference criteria for upper Sacramento River chinook salmon. California Department of Fish and Game. Inland and anadromous sport fish management and research. Project number: F-51-R. 43 pp + Appendices.

Study Summary. This study provides data on habitat availability, use, and preference of adult and juvenile fall-, late-fall, and winter-run chinook salmon in the Sacramento River from Redding to Princeton. The data was collected by the CDFG from October 1985 to July 1989. The basic information provided on chinook salmon HSC is useful as a basis for analysis of salmon flow needs in the upper Sacramento River. The HSC developed here were used with PHABSIM for the CDWR (1993) flow study. The adult and juvenile elements of this study were not as robust as originally proposed: 64 sets of depth, velocity, and substrate criteria observations were proposed for each chinook salmon life stage. Only enough fall-run data was collected to produce 6 sets for adult spawning, 10 sets for small juveniles (fingerlings), and 2 sets for large juveniles. Furthermore, observations of juveniles were made in slow, shallow water though most of the river is relatively swift and deep. Fish observations were not in the same ratio as habitat available nor were they made at night or during turbid conditions. The total number of chinook salmon observations was low. There were not enough winter-, late fall-, or spring-run chinook salmon observations to construct their suitability curves.

Sacramento River: Instream Flow and Temperature Study Needs. The Sacramento River will require considerably more attention prior to establishing instream flow requirements for its anadromous fishery. Thusfar studies have concentrated on fall-run chinook salmon. These studies require complete review to determine their acceptability. Other chinook salmon runs and anadromous species are found in the Sacramento River. Their habitat requirements should be studied. Winter-run chinook salmon is of particular concern due to its current endangered status. The importance, life stage timing, and river locations of the anadromous fish found in the Sacramento River need to be determined. Following these determinations, specific investigations can be recommended.

To recommend a flow regime for the upper Sacramento River the following relationships need to be determined: 1) Water temperature and quality versus streamflow (macrohabitat); 2) Hydraulic and structural conditions versus streamflow (microhabitat); 3) Adult immigration conditions versus streamflow; and 4) Juvenile emigration conditions versus streamflow. To determine the first relationship a predictive water temperature model will be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. IFIM study sites will need to be established for physical habitat data collection and HSC will have to be tested or collected for the evaluation species.

The emigration and immigration problems and conditions relate primarily to instream barriers which block passage and to diversions and pumping which impair passage and cause mortality. Investigations of these problems will be needed. Short duration high flows (pulse flows) have often been recommended to attract adults into a river and convey smolts to the sea. High spring flows appear to be correlated with escapement two years later (see CDFG, 1987). However, further scientific investigation of pulse flow effectiveness is needed.

A coordinated well planned effort is needed on the upper Sacramento River. As suggested by CDFG and CDWR (1993) a multi-agency team should be developed to address fishery concerns and flow needs in the upper Sacramento River. The CVPIA fish restoration program should enable the completion of this work.

CLEAR CREEK

Study

California Department of Water Resources. **1986**. Clear Creek fishery study. California Department of Water Resources Northern District, Red Bluff, California. 69 pp.

Study Summary. This investigation of fishery rehabilitation and recreational enhancement opportunities in the Clear Creek area was done to balance instream water for fish and wildlife with other uses. The CDFG, under contract with CDWR, conducted a 2-year fishery study. Flow needs for chinook salmon and steelhead trout were determined using the IFIM process for the entire 16.5 miles below the Whiskeytown Dam. Available habitat was predicted for chinook salmon and steelhead trout spawning and rearing using PHABSIM. Water temperature versus flows were measured for two experimental flow releases. Water quality parameters were measured. Agreement between CDWR, CDFG, USFWS, and the US Bureau of Reclamation (USBR) established fishery flows. Habitat improvement goals are identified. This is the most recent flow study in Clear Creek (D. Denton, B. Mendenhall; pers. comm.).

Clear Creek: Instream Flow and Temperature Study Needs. Sec. 3406 (b) 12 of the CVPIA specifically states that a comprehensive program to provide flows which allow sufficient spawning, incubation, rearing and out-migration for salmon and steelhead in Clear Creek be implemented. Flows should be determined by the IFIM process conducted by the CDFG after Clear Creek has been restored and a new fish ladder has been constructed at the McCormick-Saeltzer Dam.

To recommend a flow regime for Clear Creek the following relationships need to be determined: 1) Water temperature and quality versus streamflow (macrohabitat); 2) Hydraulic and structural conditions versus streamflow (microhabitat); 3) Adult immigration conditions versus streamflow; and 4) Juvenile emigration conditions versus streamflow. To determine the first relationship a predictive water temperature model will be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. Additional physical habitat data may have to be collected if the CDWR (1986) flow study is found to be unacceptable.

The emigration and immigration problems and conditions relate primarily to instream barriers and diversions which block passage. The CDWR (1986) identifies many of these problems. Further passage problems exist for fish once they reach the Sacramento River. Short duration high flows (pulse flows) have been recommended to attract adults into the creek (see CDWR, 1986). Further investigation of pulse flow effectiveness is needed.

COW CREEK

Cow Creek enters the Sacramento River in Shasta County near the town of Anderson. Fall-, late fall-, spring-run chinook salmon and steelhead trout are found in this creek. Hydropower production and agricultural diversions are found in the Cow Creek drainage. Loss of habitat and instream flows in this drainage are primarily a result of livestock production. Instream flow studies should be done to establish flows for the anadromous fish of Cow Creek (Reynolds et al., 1993).

BATTLE CREEK

Battle Creek joins the Sacramento River in Shasta County south of the town of Cottonwood. Fall-, winter-, and spring-run chinook salmon and steelhead trout have historically used this creek. Hydroelectric (operated by PG&E, FERC # 1121) and agricultural diversions are found on this creek. A flow study concentrating on chinook salmon and steelhead trout has been conducted on Battle Creek above the Coleman National Fish Hatchery by T. Pain and Associates under contract to the CDFG. The study report has not been completed. A temperature model was also developed. Draft reports are being reviewed (CDFG, pers. comm.). Restoration efforts in Battle Creek should focus on winter- and spring-run chinook salmon and steelhead trout (Reynolds et al., 1993).

Study

Vogel, D. A. **1982**. Preferred spawning velocities, depths, and substrates for fall-run chinook salmon in Battle Creek, California. US Fish and Wildlife Service, Red Bluff, California. pp.

Study Summary. Spawning preference curves for water velocity and depth were developed for fall-run chinook salmon in Battle Creek. Observations of spawning substrate sizes were also made. The velocity curves were similar to Bovee (1978). Depth curves were also similar to Bovee (1978). Because Battle Creek is shallow, relative probability of use could not be determined for depths greater than 67.1 cm.

COTTONWOOD CREEK

Cottonwood Creek drains the west side of the Central Valley and enters the Sacramento River in Shasta County near the town of Anderson. Fall-, late fall-, and spring-run chinook salmon and steelhead trout use this creek. There are no major diversions on this creek. However, there are a number of gravel mines which damage spawning areas, reduce recruitment of spawning gravel into the Sacramento River, and cause stranding problems. Poor land-use practices in the upper watershed have resulted in siltation of the existing gravels (see Reynolds et al., 1993).

Study

Brown, C. J. **1979**. An analysis of stream flows for fishes of Cottonwood Creek, California. California Department of Fish and Game draft report. 24 pp.

Study Summary. Streamflow and water temperature needs of chinook salmon, smallmouth bass, and Sacramento sucker in Cottonwood Creek were investigated. Studies were conducted to determine the amount of microhabitat available at different flows. Salmon spawning habitat area was determined by the "traditional" CDFG method which based suitability criteria on depth > 24 cm, velocity of 0.4 to 1.1 m^3/s, and gravel sizes as in Puckett and Hilton (1974). Available salmon incubation and rearing habitat was determined using PHABSIM. Fish life history criteria were developed by Federal and State biologists and HSC were established by analysis of observations. Probability of use criteria were developed for chinook salmon life stages. Flow recommendations were made for dry and normal years.

ANTELOPE CREEK

Antelope Creek enters the Sacramento River from the east near the town of Red Bluff. Fall-, late fall-, and spring-run chinook salmon and steelhead trout use this creek. Spring-run chinook salmon are given high priority in this creek by the CDFG (Reynolds et al., 1993). The creek is little altered above the valley floor. There are two water diversions at the canyon mouth on Antelope Creek. One is operated by the Edwards Ranch and the other by the Molinos Mutual Water Company. When both are in operation the lower reach is dry and salmon can not enter the creek (Reynolds et al., 1993).

MILL CREEK

Mill Creek originates on the southern slopes of Mt. Lassen and enters the Sacramento River north of the town of Tehama. Three dams on the lower eight miles of the stream divert most of the natural flow. Two of the dams have functioning fish ladders and the third has a poorly designed ladder. Fall-, spring-, and occasionally late fall-run chinook salmon and steelhead use Mill Creek. Mill Creek is important to spring-run salmon. An instream flow study to determine minimum passage flows and a flow-temperature study to determine flows needed to protect salmon and steelhead are recommended (Reynolds et al., 1993).

DEER CREEK

Deer Creek originates on the slops of Butt mountain and enters the Sacramento River near Woodson Bridge State Park. Fall-, late fall-, and spring-run chinook salmon and steelhead trout use Deer Creek. Deer Creek has the greatest potential for spring-run chinook salmon. An instream flow study to determine passage flows and a flow-temperature study to determine flows needed to protect salmon and steelhead have been recommended (Reynolds et al., 1993). The major problems on this creek are irrigation diversions and flood control channelization.

BIG CHICO CREEK

Big Chico Creek enters the Sacramento River from the east near the city of Chico. The M&T pumps located near the mouth are the only major diversion. During their operation flow reversals cause a total loss of downstream migrants. Lindo Channel serves as a flood control diversion and often supports salmon. Spring-, fall-, and late fall-run chinook salmon and steelhead trout use Big Chico Creek (Reynolds et al., 1993).

BUTTE CREEK

Butte Creek enters the Sacramento River at Butte Slough and through the Sutter Bypass and Sacramento slough. Fall-, late fall-, and spring-run chinook salmon and steelhead trout use Butte Creek. Numerous dams and diversions cause fish passage problems.

OTHER SMALLER SACRAMENTO RIVER TRIBUTARIES

Most of the west side tributaries are unsuitable for anadromous fish because they dry before reaching the Sacramento River and/or have intermittent flows (See Reynolds et al., 1993). Pine Creek enters the Sacramento

River south of Hamilton City. This creek supports chinook salmon and steelhead trout. There are no major diversions on Pine Creek. Mud Creek, which enters Big Chico Creek near its mouth, supports fall-run chinook salmon. Paynes Creek enters the Sacramento River from the east near Red Bluff and is used by fall-run chinook salmon and steelhead trout. There are a number of small water diversions on Paynes Creek (Reynolds et al., 1993).

Sacramento River Tributaries: Instream Flow and Temperature Study Needs. Actions to benefit anadromous fish in Sacramento River tributaries should be developed on a stream by stream basis. Reynolds et al. (1993) provides a detailed overview of many of these streams and actions to benefit the anadromous fish species therein. Flow and temperature modeling studies are appropriate only for streams with regulated flows. In order to make flow recommendations for theses streams micro- and macro-habitat versus streamflow relationships and migration barriers need to be determined. Predictive water temperature models, establishment of IFIM study sites for physical habitat data collection, and HSC will have to be developed and/or selected. A coordinated well planned effort is needed for all these "smaller" Sacramento River tributaries.

FEATHER RIVER

Flow and temperature modeling studies for anadromous fish are currently being conducted on the Feather River by the CDFG and CDWR (CDWR, 1993a). The CDWR has assisted in collecting field data for the Feather River flow study (B. Mendenhall, pers. comm.).

Study

California Department of Water Resources and California Department of Fish and Game. **1991**. Proposed study plan for the Lower Feather River. CDWR and CDFG Sacramento, California. Prep. for SWRCB, Sacramento, California. 53 pp.

Study Summary. This proposed study plan for the lower Feather River was developed by CDWR and CDFG for the SWRCB as a result of a CDWR petition for a permit to transfer water from the Yuba County Water Agency to the State Water Project. The SWRCB requested a study of the impacts of the proposed project on the fish, wildlife, recreation, and agricultural diversion in the Feather River drainage. The IFIM and water temperature modeling using SNTEMP were the tools identified to evaluate the proposed action. The study will concentrate on the lower Feather River between Oroville Dam and the confluence with the Sacramento River. The proposed physical data collection will follow PHABSIM methodology. Site specific HSC development emphasizing chinook salmon spawning was proposed. Other evaluation species are steelhead trout and American Shad. The site specific HSC are proposed to be developed if sufficient observations (150-200) can be made. Habitat types were mapped, critical reaches were identified, and previously studied and proposed transect locations were identified. This study is now nearing completion.

Study

Painter, R. E., Wixom, L. H., and S. N. Taylor. **1977**. An evaluation of fish populations and fisheries in the post-Orvoville project Feather River. California Department of Fish and Game. 56 pp.

Study Summary. The objectives of this 8-year study were to determine if project operations caused changes in fish populations, recommend changes in operations to prevent fish losses, and enhance fish survival and production. Fish were not exposed to low flows during this study as it occurred during a wet period. Salmon spawning habitat availability was studied in three riffles by measuring water depth, water velocity, and substrate suitability at 1.5 m intervals along transects in each riffle. Gravel suitability was based on those in Warner

(1953). Depths between 0.2 and 1.2 m and velocities between 0.3 and 1.1 m/sec were considered suitable for salmon spawning. Flow recommendations were made for salmon spawning and to protect redds. Water temperature recommendations for May and June were also made. Because fish were not exposed to low flow conditions, this study appears to be of little use.

Study

Kier, W. M. **1964**. The streamflow requirements of salmon in the Lower Feather River, Butte County, California. California Department of Fish and Game. 18 pp.

Study Summary. This report presents the final pre-project evaluation of the effects of the Oroville Project on fish and wildlife. The objective was to provide the CDWR with final recommendations for preservation and enhancement of the resources. This study concentrates on chinook salmon spawning. Habitat criteria were gravel conditions as in Warner (1953), water velocity at 0.3 ft above the stream bed between 1.0 and 3.0 ft/sec, and depth greater than 0.8 ft. Surveys were made between Sutter Butte Dam and Honcut Creek. Three riffles were selected and divided into 100-foot squares. The gravels were sampled for spawning suitability. Water depths and velocities were measured. A spawning flow was recommended to preserve the existing population.

Feather River: Instream Flow and Temperature Study Needs. The CDWR should complete their studies to determine the optimal flow and temperature values for this fishery. Flow needs for all anadromous fish found in the Feather River must be determined. Thusfar studies have concentrated on fall-run chinook salmon spawning. Other chinook salmon runs and anadromous species are found in the Feather River. Their habitat requirements should be studied. The importance, life stage timing, and river locations of the anadromous fish found in the Feather River need to be determined. Following these determinations, additional investigations can be recommended.

To recommend a flow regime for the Feather River the following relationships need to be determined: 1) Water temperature and quality versus streamflow (macrohabitat); 2) Hydraulic and structural conditions versus streamflow (microhabitat); 3) Adult immigration conditions versus streamflow; and 4) Juvenile emigration conditions versus streamflow. To determine the first relationship a predictive water temperature model will be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. IFIM study sites will need to be established for physical habitat data collection and HSC will have to be tested or collected for evaluation species. It is anticipated that the flow study being conducted by the CDWR will address these issues.

YUBA RIVER

Study

California Department of Fish and Game. **1991b**. Lower Yuba River fisheries management plan. California Department of Fish and Game stream evaluation report no. 91-1. 197 pp.

Study Summary. This report presents data collected by Beak Consultants Inc. (see Beak, 1988), under contract to the CDFG, on the habitat requirements of fish and wildlife of the lower Yuba River during 1986-88. The objective of the management plan is to identify problems and fishery management needs of chinook salmon, steelhead trout, and American shad in the 24 mile stretch of the river from Englebright Dam to the confluence with the Feather River. A stated goal of this study was to predict available microhabitat using PHABSIM for all life stages of fall and spring-run chinook salmon, steelhead trout, and American shad. However, available microhabitat predictions were only made for fall-run chinook salmon and steelhead trout. Fall-run chinook salmon HSC were developed from site specific observations of spawning, fry, and juvenile life stages. Steelhead trout HSC were derived from the literature. Another goal was to evaluate water temperatures downstream of Englebright Dam. The water temperature model SNTEMP was used to predict average monthly water temperatures for different flows. Temperature criteria for the evaluation species were compared with water temperatures in the river. The CDFG makes flow and temperature recommendations to optimize conditions for anadromous fish in the lower Yuba River. The CDFG also provides recommendations for additional studies to improve their flow and temperature suggestions (see CDFG, 1991b).

Study

Bookman-Edmonston Engineering, Inc., and Jones & Stokes Inc. **1990**. Scoping report and study plan for the Lower Yuba River fishery study. Prep. for Yuba County Water Agency, Marysville, CA.

Study Summary. Additional work to determine specific HSC for steelhead trout would be unsuccessful. Habitat-discharge relationship should not be used as the primary information to determine Yuba River American shad flow needs. The HEC5Q model will be used to model water temperatures in New Bullards Bar and the Englebright reservoirs to access water temperatures in the lower Yuba River under five alternative project operations. This model was completed for the Yuba River hearings (Bookman-Edmonston, pers. comm.).

Study

Beak Consultants Inc. **1988**. Yuba River fisheries investigations, 1986-88. Summary report of technical studies on the Lower Yuba River, California. Draft report prep. for the California Department of Fish and Game. 178 pp.

Study Summary. Beak Consultants Inc., was contracted by the CDFG (see CDFG, 1991b) to investigate the fishery resources in the lower Yuba River from Englebright Dam to the confluence with the Feather River. The focus is on chinook salmon and includes: 1) Fish habitat mapping; 2) Assessment of fluvial geomorphology; 3) Assessment and investigation of fishery effects from diversions, fish passage, migration barriers, and riparian vegetation; 4) Assessment of water quality; 5) River temperature modeling; 6) Characterizing the fish community; 7) Developing chinook salmon HSC; and 8) Developing instream flow criteria. The PHABSIM component of the IFIM was used to predict available microhabitat for fall-run chinook salmon. Site-specific HSC for spawning, fry, and juvenile life stages were developed.

Lower Yuba River water temperatures were modeled using the SNTEMP model combined with 7 years of meteorological and hydrological data. The temperature model provided monthly averages, and simulations were run to coincide with important chinook salmon life stages. Chinook salmon physiological temperature ranges from the literature were combined with WUA predictions and water temperature simulations to estimate the total habitat area available at different flows.

Yuba River: Instream Flow and Temperature Study Needs. The Yuba River will require some further attention prior to establishing instream flow requirements for its anadromous fishery. Thusfar studies have concentrated on fall-run chinook salmon. Spring-run chinook salmon and other anadromous species are found in the Yuba River. Their habitat requirements should be studied. The importance, life stage timing, and river locations of the anadromous fish found in the Yuba River need to be determined. Following these determinations, specific investigations can be recommended.

The CDFG (1991b) and Beak (1988) studies have developed macro- and microhabitat versus streamflow relationships for Yuba River chinook salmon and steelhead trout. Adult immigration conditions versus streamflow and juvenile emigration conditions versus streamflow were also covered. To better determine the relationship between water temperature and streamflow, a predictive water temperature model operating on daily averages may be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. Further investigation of pulse flows is needed.

BEAR RIVER

The Bear River once supported substantial chinook salmon and steelhead runs. The instream flow study prepared for the Garden Bar Project is technically flawed (Reynolds et al., 1993). Flow and temperature study needs are not identified in Reynolds et al. (1993). A flow study may be conducted as mitigation for a water development if the project receives funding (P. Lickwar, pers. comm.). Other flow studies in relation to PG&E projects may have been conducted. A formal write up of the Garden Bar flow study was not done (T. Richards, pers. comm.).

Study

Response to FERC letter dated 11 April **1985** for the Garden Bar Project, FERC no. 5222 additional information items. Fish, wildlife, and botanical resources. In FERC files FWS Sac., CA.

Study Summary. This letter presents the results of a flow study conducted on the lower Bear River. The purpose was to determine the instream flow needs of chinook salmon. The primary focus was on flows needed for chinook salmon spawning. Data was collected on microhabitat of juvenile salmon. Habitat availability data was collected. Two sites representing the upper and lower portions of the river were studied. The data was used to create habitat suitability indices for chinook salmon spawning and rearing. These criteria were used in combination with field data to construct preliminary curves of spawning and juvenile habitat at different flows. Poor visibility delayed the collection of microhabitat data until May when flows were low and temperatures high. These observations reflect low-flow and thermally stressful conditions.

Bear River: Instream Flow and Temperature Study Needs. The Bear River will require considerably more attention prior to establishing instream flow requirements for its anadromous fishery. Thusfar studies have concentrated on fall-run chinook salmon spawning. Other chinook salmon runs and anadromous species have historically used the Bear River. Their habitat requirements should be studied. The importance, life stage timing, and river locations of the anadromous fish found in the Bear River need to be determined. Following these determinations, specific investigations can be recommended.

To recommend a flow regime for the Bear River the following relationships need to be determined: 1) Water temperature and quality versus streamflow (macrohabitat); 2) Hydraulic and structural conditions versus streamflow (microhabitat); 3) Adult immigration conditions versus streamflow; and 4) Juvenile emigration conditions versus streamflow. To determine the first relationship a predictive water temperature model will be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. IFIM study sites will need to be established for physical habitat data collection and HSC will have to be tested or collected for the evaluation species.

The emigration and immigration problems and conditions relate primarily to instream barriers which block passage and to diversions and pumping which impairs passage and causes mortality. Investigations of these problems will be needed. Further investigation of pulse flow effectiveness is needed.

A coordinated well planned effort is needed on the Bear River. A multi-agency team should be developed to address anadromous fishery concerns and flow needs in the Bear River. The CVPIA fish restoration program should enable the completion of this work. Other non-flow related issue should be addressed.

LOWER AMERICAN RIVER

Study

US Fish and Wildlife Service. **1993b**. America River water resources investigation of the US Bureau of Reclamation, phase 1-water needs assessment. Planning report. US Fish and Wildl. Serv. Ecol. Serv. Div., Sacramento, California. 33 pp.

Study Summary. This report compiles information on instream flows needed to maintain fish and wildlife in a number of Central Valley rivers. The legally guaranteed minimum instream flows are < 40% of the known need for anadromous fisheries in the Central Valley. The minimum legally required flow for the American River is ca. 25% of the biological need. Flows developed by the USFWS (1985) are recommended until further studies are completed.

Study

Beak Consultants Inc. **1992**. Fish and wildlife investigations for Folsom Dam and Reservoir reoperation. Beak Consultants Inc., Prep. for U.S. Army Corps of Engineers.

Study Summary. Habitat discharge relationships obtained directly from USFWS (1983, 1985) were used to determine flow suggestions for chinook salmon. Habitat discharge relationships for steelhead trout were obtained by running the PHABSIM model using steelhead HSC for spawning and fry from Bovee (1978) and for juveniles from Smith (1986). The WUA's were weighted in proportion to their representation of upstream area to produce a single value of fish habitat (WUA). The weighting was based on habitat mapping conducted by Beak in 1988. Physical habitat (WUA) duration was estimated by hydraulic year type (40, 30, 30) and compared among year types to determine available habitat for the different project alternatives. Flow fluctuations were modeled.

Temperature modeling was done to determine the effects of Folsom Dam reoperation on water temperature in the lower American and Sacramento Rivers. The effects of anticipated meteorological conditions on river water temperature were considered. The QUAL2E model was used to model the rivers and simulate water temperatures in an hourly mode for calendar years. The CE-THERM-R1 model was used to model reservoir temperatures. All models were calibrated with 1990 data. The river water temperature model used an hourly time step and a reach length of 0.2 mi. Minimum and maximum daily water temperatures were plotted for both observed and simulated data.

Study

Snider, W. M., D. B. Christophel, B. L. Jackson, and P. M. Bratovich. **1992**. Habitat characterization of the lower American River. California Department of Fish and Game.

Study Summary. This is one of several reports addressing priority studies that evaluate factors affecting flow requirements of juvenile chinook salmon in the lower American River. The results will be incorporated in the IFIM process to determine optimum fishery flows. The objective of this investigation was to determine the composition and distribution of aquatic habitats in the lower American River. A geomorphically based habitat classification system was developed to characterize habitat in the lower American River. Areal photos and field visits were used to habitat-type the river. Habitats were typed at flows of 28 m^3/s.

Study

Snider, W. M., T. A. Jackson, P. M. Bratovich, and L. Carson. **1992**. Hydraulic simulation of the lower American River. Lower American River habitat studies. California Department of Fish and Game

Study Summary. One of several technical reports addressing priority studies on the lower American River that evaluate factors affecting flow requirements of juvenile chinook salmon. The specific objective was to develop a calibrated model that could simulate water depth and velocity over a range of flows in the lower American River. The results of this study will be incorporated into the IFIM process to determine optimum fishery flows. A major portion of PHABSIM is hydraulic simulation. Hydraulic conditions were computer simulated from physical and hydraulic data collected at selected locations along the lower American River. The results from the habitat characterization study were used to assign transect locations (Snider et al., 1992). Water depth, velocity, and surface elevation were incorporated into the PHABSIM model to simulate water depth and velocity at different discharge levels.

Study

Christensen, C. L. and G. T. Orlob. **1988**. Preliminary report: Temperature modeling of the Sacramento and American Rivers. Prep. for California Department of Fish and Game by Dept. Engineering U.C. Davis. Davis, California.

Study Summary. This study represents a preliminary evaluation of mathematical models currently available to simulate water temperatures in streams and reservoirs. A concern about the predictive capability of these models is whether they can be used to access temperature effects of critical consequence to the anadromous fisheries of the Sacramento and American Rivers. The primary objective of this investigation was to determine the sensitivity of the USBR's mathematical model for predicting stream and reservoir water temperatures in the Sacramento and American river systems. A second objective was to access the significance of daily versus monthly simulations of water temperature and flow and to access the adequacy and sensitivity of the models. The USBR model simulates average monthly values, actual water temperature values vary on a daily basis, and water temperature should be modeled as daily averages for fishery requirements.

Study

Leidy, G. R. and S. Li. **1987**. Analysis of river flows necessary to provide water temperature requirements of anadromous fishery resources of the lower American River. (lower American River court reference, EDF V EBMUD, exhibit no. 69-A). Prep. for McDonough, Holland, and Allen, Sacramento, CA.

Study Summary. This report accesses the effects of reduced stream flows on the thermal conditions and fish resources of the lower American River. The objectives were to describe the effects of existing water temperatures on the life stages of three anadromous fish species (chinook salmon, steelhead trout, and American shad), to establish changes in existing water temperatures that result from changing flow, and to accesses water temperature-related impacts of changing flows. The results of these studies are contained in two large appendices. The first details the laboratory and field study of American River chinook salmon temperature tolerance experiments, and the second presents the results of a lower American River water temperature modeling study. The objective of the optimal temperature experiments was to experimentally determine optimal and stress zone water temperatures for American River juvenile chinook salmon fed maximum rations. Temperature ranges derived from the literature for various life stages of chinook salmon, steelhead trout, and American shad are provided in a table. Experimental results set the upper optimum temperature for juvenile chinook salmon at 13.3 C. The water temperature model QUAL2E was used to predict monthly average water temperature under different flows during April through October in the lower American River. Flow recommendations are not made.

Study

Snider, W. M. and E. Gerstung. **1986.** Instream flow requirements of the fish and wildlife resources of the lower American River, Sacramento County, California. California Department of Fish and Game. 33 pp.

Study Summary. Data collected over 35 years on the instream flow requirements of the fish and wildlife resources of the lower American River were evaluated. A range of flows encompassing optimum habitat conditions for each life stage of chinook salmon were identified. Optimum flow ranges for American shad, steelhead trout, and striped bass were identified and combined with chinook salmon requirements to determine an optimal flow schedule. CDFG considers the maximum flow in each flow range as optimal. Flows should mimic historic seasonal variations.

Study

US Fish and Wildlife Service. **1985.** Flow needs of chinook salmon in the lower American River. Final report on the 1981 lower American River flow study. Prep. by US Fish and Wildl. Serv. Ecol. Serv. Div., Sacramento, California. For US Bureau of Reclamation mid-Pacific Region, Sacramento, California. 22 pp.

Study Summary. This study examines the relationship between instream flow and the fish and wildlife resources in the lower American River. The PHABSIM component of the IFIM was used to predict available microhabitat for fall-run chinook salmon adult spawning and two juvenile life stages. Four reaches from the Nimbus Dam to the confluence with the Sacramento River (23 RM) were measured at calibration flows of 14, 34.2, and 69.3 m^3/s during August and September 1981. Habitat suitability criteria were developed for chinook salmon spawning, juvenile < 50 mm, and juvenile > 50 mm rearing using 2 years of field studies combined with the literature and the expertise of various biologists. Under the existing flow, water temperatures at the mouth of the American River occasionally reach marginal to limiting levels for chinook salmon prior to 1 July. Water temperature and flow recommendations are made.

Study

Kelley, D. W., P. M. Bratovich, D. H. Dettman, and H. Rooks. **1985.** The effects of streamflow on fish in the lower American River. D. W. Kelley and Associates Newcastle, California.

Study Summary. Reevaluates USFWS (1981) data. Based on current information this report attempts to define a range of optimum flows for chinook salmon in the lower American River and define flows which are best for fish. Current spring flows are to high to produce a large amount of rearing habitat and keep the temperatures too low for good growth.

Study

Rich, A. A. and G. R. Leidy. **1985.** Evaluation of instream flow requirements for fall-run chinook salmon (*Oncorhynchus tshawytscha*) in the lower American River, California. Prep. for McDonough, Holland, and Allen. Sacramento, California.

Study Summary. Presents an independent analysis of the instream flow needs for American River fisheries using existing data. The initial assignment was to evaluate the flow needs for chinook salmon while acknowledging that steelhead trout, American shad, and striped bass will need to be evaluated later. The objectives, methods, analysis, quality, and assumptions of two previous flow studies were examined. The flow recommendations were found to be speculative when all factors were considered. Water temperature was found to be a major constraint on salmon production in the lower American River.

American River: Instream Flow and Temperature Study Needs. Flow studies on the American River completed prior to 1986 are likely obsolete due to channel changes caused by flooding that year. Past flow studies have generally concentrated on juvenile fall-run chinook salmon. These studies require complete review to determine their acceptability. The lower American River will require more attention prior to establishing instream flow requirements for its anadromous fishery. Other chinook salmon runs and anadromous species are found in the American River. Their habitat requirements should be studied. The importance, life stage timing, and river locations of the anadromous fish in the lower American River need to be determined. Following these determinations, specific investigations can be recommended.

To recommend a flow regime for the lower American River the following relationships need to be determined: 1) Water temperature and quality versus streamflow (macrohabitat); 2) Hydraulic and structural conditions versus streamflow (microhabitat); 3) Adult immigration conditions versus streamflow; and 4) Juvenile emigration conditions versus streamflow. To determine the first relationship a predictive water temperature model will be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. HSC will have to be tested or collected for the evaluation species.

The emigration and immigration problems and conditions relate primarily to instream barriers which block passage and diversions and pumping which cause passage problems and mortality. Investigations of these problems will be needed. Further investigation of pulse flow effectiveness is needed.

A coordinated well planned effort is needed for the lower American River. Much of the work has been done. The CVPIA fish restoration program should enable the completion of this work. Other non-flow related issue should be addressed.

COSUMNES RIVER

There are no water storage reservoirs on this river and only one diversion dam. Fall-run chinook salmon use this river when fall rains provide passage flows (Reynolds et al., 1993). Assessment of water needs for fish and wildlife in the Cosumnes River is lacking and flow and temperature modeling studies are needed (USFWS, 1993b).

MOKELUMNE RIVER

Study

California Department of Fish and Game. **1991a**. Lower Mokelumne River fisheries management plan. Stream flow requirements program. California Department of Fish and Game. 234 pp.

Study Summary. This study evaluates data collected by EBASCO Services Inc., for the CDFG on the lower Mokelumne River during 1986-87 from the Comanche Dam to the confluence with the Sacramento-San Joaquin Delta. Instream flow and temperature modeling studies were done. Sufficient site-specific HSC data were collected for chinook salmon adult spawners and fry. There were not enough observations of juvenile chinook salmon and all life stages of steelhead trout to determine site-specific HSC. The small size of the American shad population in this river made it impossible to develop HSC. Optimum and preference water temperatures for fall-run chinook salmon, steelhead trout, American shad, and striped bass were determined from the literature. Water temperatures were modeled using SNTEMP on a bi-monthly bases for several water year types and flow regimes. The PHABSIM component of the IFIM was applied to the lower Mokelumne River to predict available microhabitat for all life stages of chinook salmon and steelhead trout. Study sites were chosen to represent habitats available in the river. Flow and temperature recommendations for normal, wet, and dry water years were made. The flow recommendations are considered minimum flows to provide the maintenance of chinook salmon, steelhead trout, American shad, and striped bass in the lower Mokelumne River. Spring and fall pulse flows were not evaluated.

Mokelumne River: Instream Flow and Temperature Study Needs. The Mokelumne River will require some attention prior to establishing instream flow requirements for its anadromous fishery. The above study concentrated on fall-run chinook salmon and steelhead trout. Striped bass and American shad are found in the Mokelumne River. Their habitat requirements may need further study.

The CDFG (1991a) study developed macro- and microhabitat versus streamflow relationships for Mokelumne River chinook salmon and steelhead trout. Adult immigration conditions versus streamflow and juvenile emigration conditions versus streamflow were also covered. To better determine the relationship between water temperature and streamflow, a predictive water temperature model operating on daily averages may be needed. These results can be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. Further investigation of pulse flow effectiveness is needed.

CALAVERAS RIVER

Study

US Fish and Wildlife Service. **1993c**. Stanislaus River basin Calaveras River conjunctive use water program study: A preliminary evaluation of fish and wildlife impacts with emphasis on water needs of the Calaveras River. US Fish and Wildl. Serv. Ecol. Serv. Div., Sacramento, California. 24 pp.

Study Summary. This report provides preliminary flow recommendations for the Calaveras River and minimum pool recommendations at New Hogan Lake based on a limited study. The fish flows and minimum pool recommendations represent the minimum base flows necessary to maintain an anadromous fishery in the Calaveras River. Flow suggestions are based on preliminary instream flow measurements and PHABSIM-predicted available microhabitat for fall- and winter-run chinook salmon. Estimates for fall- and winter-run chinook salmon are based on fall-run HSC developed by the USFWS for the Stanislaus, Yuba, and American Rivers. Preliminarily suggested flow schedules for fall- and winter-run chinook salmon spawning are presented for dry, normal, and wet years. Because the winter-run chinook salmon have persisted without the benefit of fishery flow releases, restoration of this run is most feasible in the Calaveras River.

Calaveras River: Instream Flow and Temperature Study Needs. The Calaveras River will require considerably more attention prior to establishing instream flow requirements for its anadromous fishery. Thusfar study has concentrated on fall- and winter-run chinook salmon. Other anadromous species may use the Calaveras River. Their habitats should be studied. Winter-run chinook salmon is of particular concern due to its current endangered status. The importance, life stage timing, and river locations of the anadromous fish found in the Calaveras River need to be determined. Recommendations for further study include: 1). Habitat mapping to determine representative transects, 2). Refine flow need estimates based on larger number of transects, 3). Instream temperature modeling (validated by historic data) for anticipated operations, 4). Assessments of the impacts of diversions on juvenile salmon including stranding studies, 5). Evaluation of emigration timing and survival, 6). Determination of site-specific habitat preferences of salmon to further refine flow need estimates. Following these determinations, specific investigations can be recommended.

To recommend a flow regime for the Calaveras River the following relationships need to be determined: 1) Water temperature and quality versus streamflow (macrohabitat); 2) Hydraulic and structural conditions versus streamflow (microhabitat); 3) Adult immigration conditions versus streamflow; and 4) Juvenile emigration conditions versus streamflow. To determine the first relationship a predictive water temperature model will be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. More IFIM study sites will need to be established for physical habitat data collection and HSC will have to be tested or collected for the evaluation species.

The emigration and immigration problems and conditions relate primarily to instream barriers which block passage and to diversions and pumping which impair passage and causes mortality. Investigations of these problems will be needed. Further investigation of pulse flow effectiveness is needed.

A coordinated well planned effort is needed on the Calaveras River. The CVPIA fish restoration program should enable the completion of this work. Other non-flow related issue should be addressed.

STANISLAUS RIVER

Study

Aceituno, M. E. **1993**. The relationship between instream flow and physical habitat availability for chinook salmon in the Stanislaus River, California. US Fish and Wildl. Serv. Ecol. Serv. Div., Sacramento, California. 26 pp + appendices.

Study Summary. The PHABSIM component of the IFIM was used to determine available spawning and rearing microhabitat for fall-run chinook salmon in the Stanislaus River from the Goodwin Dam to the town of Riverbank. Instream flow versus physical habitat was evaluated for 3 flow regimes (3.5, 19.6, and 35 m^3/s). Flow schedules are not provided and are reliant upon the completion of further studies. These will be combined with the IFIM results to give complete flow schedules. PHABSIM outputs for steelhead trout were included, however, flow recommendations and discussions were not. Aceituno (1993) states that a water temperature model is being developed for the Stanislaus River by the USBR, the CDFG is conducting salmon survival studies and investigating the benefits of spring and fall pulse flows.

Study

Rowell, J. H. **1993**. Stanislaus River basin temperature model. US Bureau of Reclamation Mid-Pacific Region, Sacramento, California.

Study Summary. This report documents a reservoir and stream temperature model developed to evaluate the effects of alternative reservoir operations and fishery flow schedules on Stanislaus River water temperatures. The model simulates monthly mean temperature releases from New Melones operations. The model results can be interpolated to weekly means and then combined with PHABSIM predictions to estimate optimal temperature WUA for various flows, climate conditions, and initial Goodwin Dam release temperatures. The model can be used to compare alternative operational scenarios to provide cooler spawning temperatures in October and November. Flow recommendations are not made.

Stanislaus River: Instream Flow and Temperature Study Needs. The Stanislaus River will require more attention prior to establishing instream flow requirements for its anadromous fishery. Thusfar studies have concentrated on fall-run chinook salmon. The habitat requirements of other anadromous species found in the Stanislaus River should be studied. Further studies identified by Aceituno (1993) to determine a comprehensive instream flow regime directed toward protecting the Stanislaus River chinook salmon include: 1) Determining the relationship between stream flow and suitable macrohabitat conditions, and 2) Determining flows to maintain suitable temperatures for oversummering juvenile salmonids.

To recommend a flow regime for the Stanislaus River the following relationships need to be determined: 1) Water temperature and quality versus streamflow (macrohabitat); 2) Hydraulic and structural conditions versus streamflow (microhabitat); 3) Adult immigration conditions versus streamflow; and 4) Juvenile emigration conditions versus streamflow. To determine the first relationship a predictive water temperature model will be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. The HSC will have to be tested or collected for the evaluation species.

The emigration and immigration problems and conditions relate primarily to instream barriers which block passage and to diversions and pumping which impair passage and cause mortality. Investigations of these problems will be needed. Further investigation of pulse flow effectiveness is needed. A coordinated well planned effort is needed on the Stanislaus River. The CVPIA fish restoration program should enable the completion of this work. Other non-flow related issue should be addressed.

TUOLUMNE RIVER

Study

U.S Fish and Wildlife Service. **1993d**. Analysis of instream flow needs for the Lower Tuolumne River. In New Don Pedro Project FERC No. 2299 article 39 report comments. Prep. by US Fish and Wildlife Service Ecol. Serv. Div., Sacramento, California. 15 pp + appendices.

Study Summary. Fishery flows recommended in this report are based on the evaluation of 1981 (see EA, 1992) and 1992 (USFWS, 1993d) flow studies. The 1992 results were emphasized because they were based on improved methodology and biological interpretation. The PHABSIM component of the IFIM was used to predict available microhabitat for fall-run chinook salmon. Flow recommendations focus on protection, restoration, and enhancement of fall-run chinook salmon. Yearling salmon and steelhead trout are accommodated by suggested flows which provide sufficient cool water during the summer and fall. Critical, dry, normal, and wet year flow recommendations are made. The critical water year flow recommendations are suggested as the minimum threshold to insure maintenance of a year class. Temperature information from EA (1992) and criteria from CDFG documents were combined to make recommendations for the fishery.

Study

EA Engineering, Science, and Technology. **1992**. Don Pedro project fisheries study report (FERC Article 39, Project No. 2299). Prep. for Turlock Irrigation District, Turlock, California, and Modesto Irrigation District, Modesto, California. EA Engineering, Science, and Technology Lafayette, California. 82 pp + appendices.

Study Summary. Studies conducted on salmon ecology and management in the lower Tuolumne River were used to develop a management program directed at increasing the production of chinook salmon. PHABSIM data collected in two reaches during 1981 by the CDFG were reevaluated by EA. Water temperatures were modeled using the SNTEMP model combined with 11 years of hydrological and meteorological data. The temperature model predicts 5-day averages. This report provides a flow schedule for five water year types ranging from critical to median wet that will provide between 5 and 15 miles of river with temperatures suitable for salmon. Site-specific observations were used to generate HSC for spawning adult chinook salmon. Chinook salmon incubation and juvenile life stage HSC were taken from the literature.

EA (1992) states that the six ongoing research studies of stream flow and fisheries habitat in the Tuolumne River are: 1) IFIM performed by USFWS; 2) Temperature monitoring performed by the irrigation districts; 3) Flow fluctuation study performed by the districts; 4) Spawning surveys to be conducted by CDFG; 5) Smolt survival index study to be done by CDFG; and 6) Juvenile salmon studies to be preformed by the irrigation districts.

Tuolumne River: Instream Flow and Temperature Study Needs. The Tuolumne River will require more attention prior to establishing instream flow requirements for its anadromous fishery. Thusfar studies have concentrated on fall-run chinook salmon. These studies require complete review to determine their acceptability. The habitat requirements of other anadromous species found in this river should be studied.

To recommend a flow regime for the Tuolumne River the following relationships need to be determined: 1) Water temperature and quality versus streamflow (macrohabitat); 2) Hydraulic and structural conditions versus streamflow (microhabitat); 3) Adult immigration conditions versus streamflow; and 4) Juvenile emigration conditions versus streamflow. To determine the first relationship a predictive water temperature model will be needed. These results will be integrated with the microhabitat versus streamflow function generated by PHABSIM to obtain a total habitat versus streamflow relationship. This relationship must be determined for each life-stage of each evaluation species. HSC will have to be tested or collected for the evaluation species.

The emigration and immigration problems and conditions relate primarily to instream barriers which block passage and to diversions and pumping which impair passage and cause mortality. Investigations of these problems will be needed. Further investigation of pulse flow effectiveness is needed.

A coordinated well planned effort is needed on the Tuolumne River. The CVPIA fish restoration program should enable the completion of this work. Other non-flow related issue should be addressed.

MERCED RIVER

The Merced River supports fall- and late fall-run chinook salmon and steelhead trout. Flow and temperature modeling studies have not been completed to date. The CDFG plans to conduct these studies over the next three years (Reynolds et al., 1993). Three flow data sets have been collected for the Merced River flow study and a temperature model should be completed in the spring of 1994 (W. Snider, pers. comm.).

LOWER SAN JOAQUIN RIVER

The USFWS is currently finishing a flow study on the lower San Joaquin River below Friant Dam (J. Thomas, pers. comm.). Prior to 1949, the main stem of this river supported spring- and fall-run chinook salmon. Green and white sturgeon migrate up the San Joaquin River in winter and spawn in the spring. Adult sturgeon move upstream as far as the mouth of the Merced River or Mendota pool. Spawning is probably unsuccessful due to poor water quality (Moyle, 1976).

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